

**Fishery Data Series No. 13-18**

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# **Tikchik Lake System Lake Trout Assessment, Bristol Bay Management Area, 2005–2006**

by

**Craig J. Schwanke**

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April 2013

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Alaska Department of Fish and Game

Divisions of Sport Fish and Commercial Fisheries



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Weights and measures (metric)		General		Mathematics, statistics	
centimeter	cm	Alaska Administrative Code	AAC	all standard mathematical signs, symbols and abbreviations	
deciliter	dL	all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.	alternate hypothesis	H <sub>A</sub>
gram	g	all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.	base of natural logarithm	<i>e</i>
hectare	ha			catch per unit effort	CPUE
kilogram	kg			coefficient of variation	CV
kilometer	km	at	@	common test statistics	(F, t, $\chi^2$ , etc.)
liter	L			confidence interval	CI
meter	m			correlation coefficient	
milliliter	mL	compass directions:		(multiple)	R
millimeter	mm	east	E	correlation coefficient (simple)	r
Weights and measures (English)		north	N	covariance	cov
		south	S	degree (angular )	°
cubic feet per second	ft³/s	west	W	degrees of freedom	df
foot	ft	copyright	©	expected value	<i>E</i>
gallon	gal	corporate suffixes:		greater than	>
inch	in	Company	Co.	greater than or equal to	≥
mile	mi	Corporation	Corp.	harvest per unit effort	HPUE
nautical mile	nmi	Incorporated	Inc.	less than	<
ounce	oz	Limited	Ltd.	less than or equal to	≤
pound	lb	District of Columbia	D.C.	logarithm (natural)	ln
quart	qt	et alii (and others)	et al.	logarithm (base 10)	log
yard	yd	et cetera (and so forth)	etc.	logarithm (specify base)	log <sub>2</sub> , etc.
Time and temperature		exempli gratia		minute (angular)	'
		(for example)	e.g.	not significant	NS
day	d	Federal Information Code	FIC	null hypothesis	H <sub>0</sub>
degrees Celsius	°C	id est (that is)	i.e.	percent	%
degrees Fahrenheit	°F	latitude or longitude	lat. or long.	probability	P
degrees kelvin	K	monetary symbols (U.S.)	\$, ¢	probability of a type I error (rejection of the null hypothesis when true)	$\alpha$
hour	h	months (tables and figures): first three letters	Jan,...,Dec	probability of a type II error (acceptance of the null hypothesis when false)	$\beta$
minute	min	registered trademark	®	second (angular)	"
second	s	trademark	™	standard deviation	SD
Physics and chemistry		United States (adjective)	U.S.	standard error	SE
		United States of America (noun)	USA	variance	
all atomic symbols		U.S.C.	United States Code	population sample	Var var
alternating current	AC	U.S. state	use two-letter abbreviations (e.g., AK, WA)		
ampere	A				
calorie	cal				
direct current	DC				
hertz	Hz				
horsepower	hp				
hydrogen ion activity (negative log of)	pH				
parts per million	ppm				
parts per thousand	ppt, ‰				
volts	V				
watts	W				

***FISHERY DATA SERIES NO. 13-18***

**TIKCHIK LAKE SYSTEM LAKE TROUT ASSESSMENT, BRISTOL BAY  
MANAGEMENT AREA, 2005–2006**

by

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## ABSTRACT

During July of 2005 and 2006, lake trout (*Salvelinus namaycush*) were captured by angling from Tikchik, Nuyakuk, and Chikuminuk lakes and sampled for length and weight to estimate yield potential in terms of number of fish per lake per year (YPn) using a model based on lake surface area. Approximately 140 lake trout were sampled from each lake. In 2005, 40 lake trout captured in Tikchik Lake were also implanted with radio transmitters to document seasonal movements, to determine if fish from Tikchik Lake enter Nuyakuk Lake by the narrows that connect the lakes, and to locate spawning sites during September 2005. Telemetry data did not indicate significant movement into Nuyakuk Lake and there was a significant difference in the cumulative length and weight distributions of lake trout between Tikchik and Nuyakuk lakes. As a result, YPn was estimated for Tikchik and Nuyakuk lakes separately with a different minimum size for each lake. The yield potentials for Tikchik and Nuyakuk lakes respectively were 1,017 and 2,729 fish per lake per year for fish greater than 450 mm fork length and 3,035 fish per lake per year for fish greater than 400 mm fork length in Chikuminuk Lake. Current harvest levels are well below these yield potentials. Ten spawning locations were documented in Tikchik Lake.

Key words: Tikchik Lake, Nuyakuk Lake, Chikikuminuk Lake, lake trout, *Salvelinus namaycush*, yield, telemetry, spawning locations.

## INTRODUCTION

Lake trout (*Salvelinus namaycush*) support important recreational fisheries in Alaskan roadside and remote lake systems. Because of their life history, lake trout can be overexploited easily when not managed conservatively. Lake trout are characterized as having slow growth rates, low fecundity, alternate-year spawning regimes, strict habitat requirements (cold, deep, oligotrophic lakes with sufficient prey and few competitors), and extreme susceptibility to changes in habitat (Martin and Olver 1980). In the Bristol Bay region, lake trout inhabit the Tikchik, Iliamna, Naknek, and Ugashik lakes drainages.

In the Bristol Bay Management Area (BBMA), the highest catch of lake trout occurs in the Tikchik Lake system (Figure 1). The system consists of 7 lakes that are distributed from north to south (Nishlik, Slate, Upnuk, Chikuminuk, Chauekuktuli, Nuyakuk and Tikchik lakes) and are connected by the Allen and Tikchik rivers. Tikchik Lake drains the entire system into the Nuyakuk River, a tributary of the Nushagak River. These lakes are large and vary in surface area up to 14,400 ha, and in depth down to 288 m. Lake trout are present throughout the system. In addition to lake trout, other species found in the Tikchik Lake system include rainbow trout (*Oncorhynchus mykiss*), Arctic grayling (*Thymallus arcticus*), round whitefish (*Prosopium cylindraceum*), Arctic char (*S. alpinus*), humpback whitefish (*Coregonus clupeaformis*), sockeye salmon (*O. nerka*), northern pike (*Esox lucius*), least cisco (*Coregonus sardinella*), and burbot (*Lota lota*).

Due to the remoteness of the area and the diversity of other sport fish species in the region, the catch and harvest of lake trout in the Tikchik Lake system is low compared to roadside fisheries in Alaska. The sport catch of lake trout in this lake system has remained relatively stable with an average of 2,615 fish per year during the period 1991–2005 (Mills 1992-1994; Howe et al. 1995, 1996, 2001a-d; Walker et al. 2003; Jennings et al. 2004, 2006a-b, 2007, 2009). The current bag limit of lake trout in the BBMA is 4 per day and 4 in possession with no size restrictions. Harvest of lake trout from the Tikchik Lake system has averaged 124 fish per year during the period 1991–2005 (Mills 1992-1994; Howe et al. 1995, 1996, 2001a-d; Walker et al. 2003; Jennings et al. 2004, 2006a-b, 2007, 2009).

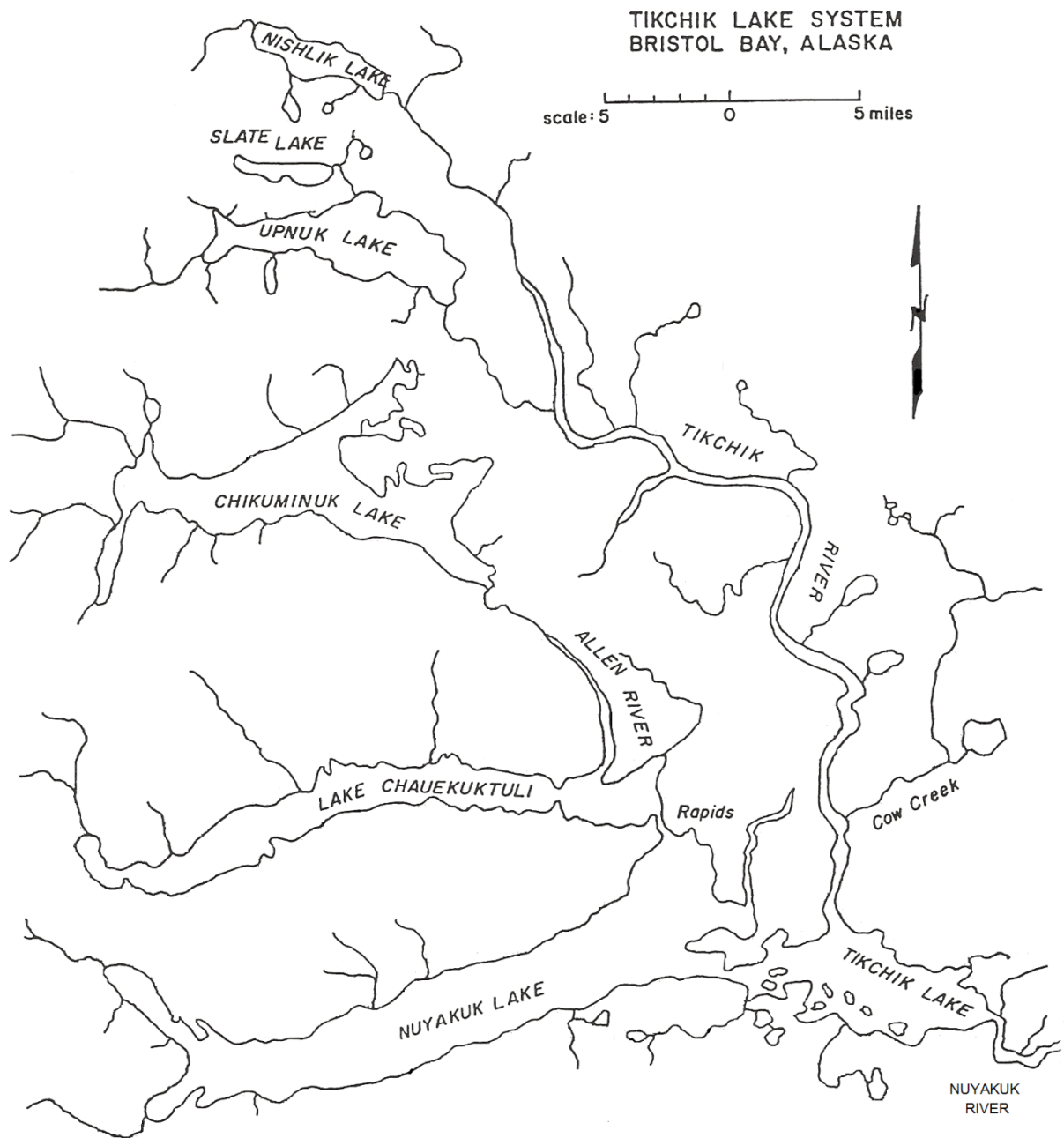


Figure 1.—Tikchik Lake system of Southwest Alaska.



The main reasons we have little information about lake trout in the Tikchik Lake system are because it is remote and because lake trout occur in low densities and in deep water. The information that is available originates from a freshwater commercial fishery that existed in the lake system in 1966 and 1967 (Yanagawa 1967) when 1,502 lake trout were harvested, yielding age and sex data. In addition, length, weight, age, and sex data were collected in 1994 and 1995 (Jaenicke et al. 1996). In the interior of Alaska, mark-recapture techniques have been used on spawning aggregations to overcome the difficulty of directly sampling the population within the lake (e.g. Szarzi and Bernard 1995). Burr (1991) used radiotelemetry to find spawning locations in Fielding Lake and to monitor movement of spawning lake trout, enabling multi-year experiments to estimate spawning abundance. Likewise, future mark-recapture studies used to estimate the spawning population in Tikchik Lake will require knowledge of spawning locations, movement of lake trout between these locations during the spawning period, and whether migration occurs between lakes during the spawning period.

The difficulty of conducting direct stock assessments has led to the use of several models to estimate potential sustained yield of lake trout from Alaskan lakes. The lake-area (LA) model (Evans et al. 1991) provides sustained yield in terms of sustainable yield biomass (kg/yr) and its use in fisheries management requires division by the estimated average weight of harvested lake trout.

To assess the lake trout stock of Tikchik Lake, it is important to know whether the LA model is only applicable to Tikchik Lake as an individual lake, or whether the areas of Tikchik Lake and the connected Nuyakuk Lake should be combined (because of mixing and similar length-weight distributions of lake trout). This decision requires a comparison of length-weight distributions and evidence of mixing between the lakes and is necessary because the LA model provides different sustainable yields for the combined system (Tikchik and Nuyakuk lakes treated as one lake) than when the lakes are treated separately.

The objectives of this study were as follows:

- 1) Obtain an estimate of the length and weight composition of lake trout in Tikchik and Nuyakuk lakes during July 2005 and Chikuminuk Lake during July 2006 for use in estimation of yield potentials by the LA model and to compare this value with current harvest estimates.
- 2) Use radio transmitters attached to male lake trout to locate spawning sites in Tikchik Lake and to determine movement of tagged fish between spawning sites and lakes with the idea of determining the feasibility of conducting a future mark-recapture abundance estimate of mature fish population size.

## **METHODS**

### **STUDY DESIGN**

#### **Radiotelemetry and Location of Spawning Sites**

This study used radiotelemetry to monitor seasonal movements of lake trout captured in Tikchik Lake and to locate spawning sites within Tikchik Lake. In July 2005, lake trout were captured by angling in Tikchik Lake. To facilitate finding spawning locations, radio transmitters were surgically implanted into 40 sexually mature male lake trout. Male lake trout spend more time on spawning grounds than female lake trout (Martin and Olver 1980), increasing the odds of

detection on a spawning site. Methods used for tracking radiotagged fish included aerial surveys from fixed-wing aircraft, tracking from boats, and a radiotracking station placed at the Narrows (the short connecting body of water between Tikchik and Nuyakuk lakes). In September 2005, prior to tracking from boats, radiotagged lake trout were located by air. Identified radiotagged fish were then located by boat after dark, when lake trout moved onto spawning sites. When a radiotagged lake trout was located in a potential spawning area (i.e., favorable water depth and substrate type), visual inspection of the site was made using hand-held spot lights and either seine was based on the substrate type (the seine hangs up on large boulders) and water depth (the seine is ineffective at depths greater than 2.5 m). Potential spawning locations were also visually located (based on habitat) and gillnets were set to determine if lake trout used these locations to spawn.

The fixed radiotracking station was installed at the Narrows during July 2005 and maintained until the end of the fall field work. Several aerial surveys were conducted over the winter months (November through April) to find overwintering locations.

### **Radio Tag Deployment and Tracking**

In July, a sample of 40 lake trout at least 450 mm FL from Tikchik Lake was selected for surgical radio tag implantation. Adult male lake trout have been shown to spend considerably longer amounts of time at spawning sites than females (Martin and Olver 1980), and therefore implanting transmitters in only males increased the chance of locating spawning sites. However, lake trout show little sexual dimorphism; therefore, the sex of the sampled fish was not known prior to implantation surgery. During surgery, an attempt was made to determine sex by looking into the body cavity through the incision made for the transmitter and inspecting the gonads. If the fish was determined to be male, it received a transmitter. If the fish was determined to be female by the presence of eggs, the fish was sutured, allowed to recover, and released.

An effort was made to deploy radio tags evenly throughout the lake, but also in proportion to abundance. Tikchik Lake was divided into 4 sections (Figure 2) and the crews initially deployed 5 radiotagged lake trout in each section. Sampling and tagging effort was spread throughout each section within the lake. Catch per unit of angling effort (CPUE) was then calculated for each section. The remaining 20 tags were then deployed in proportion to the section-specific CPUE. For example, if the CPUEs for the 4 lake sections in the first tagging session were 0.1, 0.2, 0.5 and 0.3, then the remaining 20 tags were split between the respective sections as  $0.1 \times 20 = 2$ ,  $0.2 \times 20 = 4$ ,  $0.5 \times 20 = 10$ , and  $0.3 \times 20 = 6$  tags.

Lake trout receiving a transmitter were anesthetized with clove oil as described by Anderson et al. (1997). Advanced Telemetry Systems (ATS) (Model F1840) radio transmitters with unique codes spread over 4 frequencies and a battery capacity of 339 days were surgically implanted in the coelomic cavity of selected lake trout through a 2–3 cm incision along the *linea alba*, anterior to the pelvic girdle (Hart and Summerfelt 1975). Three to 5 sutures were used to close the incision. The outlet incision for the trailing antenna was posterior to the pelvic girdle. The procedure used for the placement of trailing antenna was similar to that described by Ross and Kleiner (1982). During the surgical procedure, fresh water was poured over the gills to prevent suffocation. Radiotagged fish were retained in a tote of freshwater until equilibrium was regained and then released near the site of capture.

The movements and seasonal distribution of radiotagged fish were documented by aerial tracking surveys, a radiotracking station, and tracking by boat. The aerial surveys were conducted prespawning (late August, when the lake begins to cool down and before movement to spawning areas), at peak spawning (mid to late September), postspawning (between end of spawning season and before freeze-up), during winter, and during break-up (generally mid to late June). All frequencies were programmed into an ATS R4500C receiver–scanner. To locate fish, a fixed-wing aircraft was flown over the Tikchik Lake study area in a systematic manner while listening for transmitter signals with 2 four-element Yagi antennas mounted on the aircraft. Location of a radiotagged lake trout was recorded using a map and a GPS unit. A radiotracking station was placed between the lakes at the Narrows to record the passage of radiotagged lake trout between Tikchik and Nuyakuk lakes. If the fixed station at the Narrows indicated movement of tagged fish into Nuyakuk Lake then the aerial surveys were expanded to include Nuyakuk Lake. The radiotracking station was comprised of integrated components: a power source (supplied by Tikchik Narrows Lodge), an ATS model R2100 high frequency programmable radio receiver, data collection computer (DCC), and 2 four-element Yagi antennas. The station at the Narrows operated until October, 2005.

### **Yield Potential**

Weight and length data were collected during July and early August of 2005 from Tikchik and Nuyakuk lakes and during July of 2006 from Chikuminuk Lake. Depending on radiotelemetry results, these data, along with a quantification of lake area, were used to estimate yield potential in each or a combination of Nuyakuk and Tikchik lakes and for Chikuminuk Lake. Significant movement of radiotagged lake trout from Tikchik Lake to Nuyakuk Lake would indicate that one overall yield potential should be calculated.

### **Size Composition Sampling**

In July and August 2005, lake trout were captured in Tikchik and Nuyakuk lakes by trolling with spoons and plugs. In July 2006, lake trout were captured with the same technique from Chikuminuk Lake. Downriggers, in conjunction with an electronic depth finder, were used to effectively cover a large range of depths. Sampling was conducted throughout Tikchik and Chikuminuk lakes, and along the north shore of Nuyakuk Lake. For the purpose of sampling, Tikchik Lake was divided into 4 sections (Figure 2) and Nuyakuk Lake was divided into 6 sections (Figure 3). Chikuminuk Lake was not divided into sections. For Tikchik and Nuyakuk lakes, an attempt was made to equalize angling effort in each of the lake sections. Tikchik Lake sampling was conducted by 2 crews, each expending approximately 6 hours of effort each day, 5 days a week, until 80% (32) of the radio transmitters had been deployed (see below). All lake trout captured were measured for fork length (FL), weighed, and tagged with a Floy<sup>1</sup> tag. Sex was also determined for fish deployed with radio tags.

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<sup>1</sup> Product names used in this publication are included for completeness but do not constitute product endorsement.

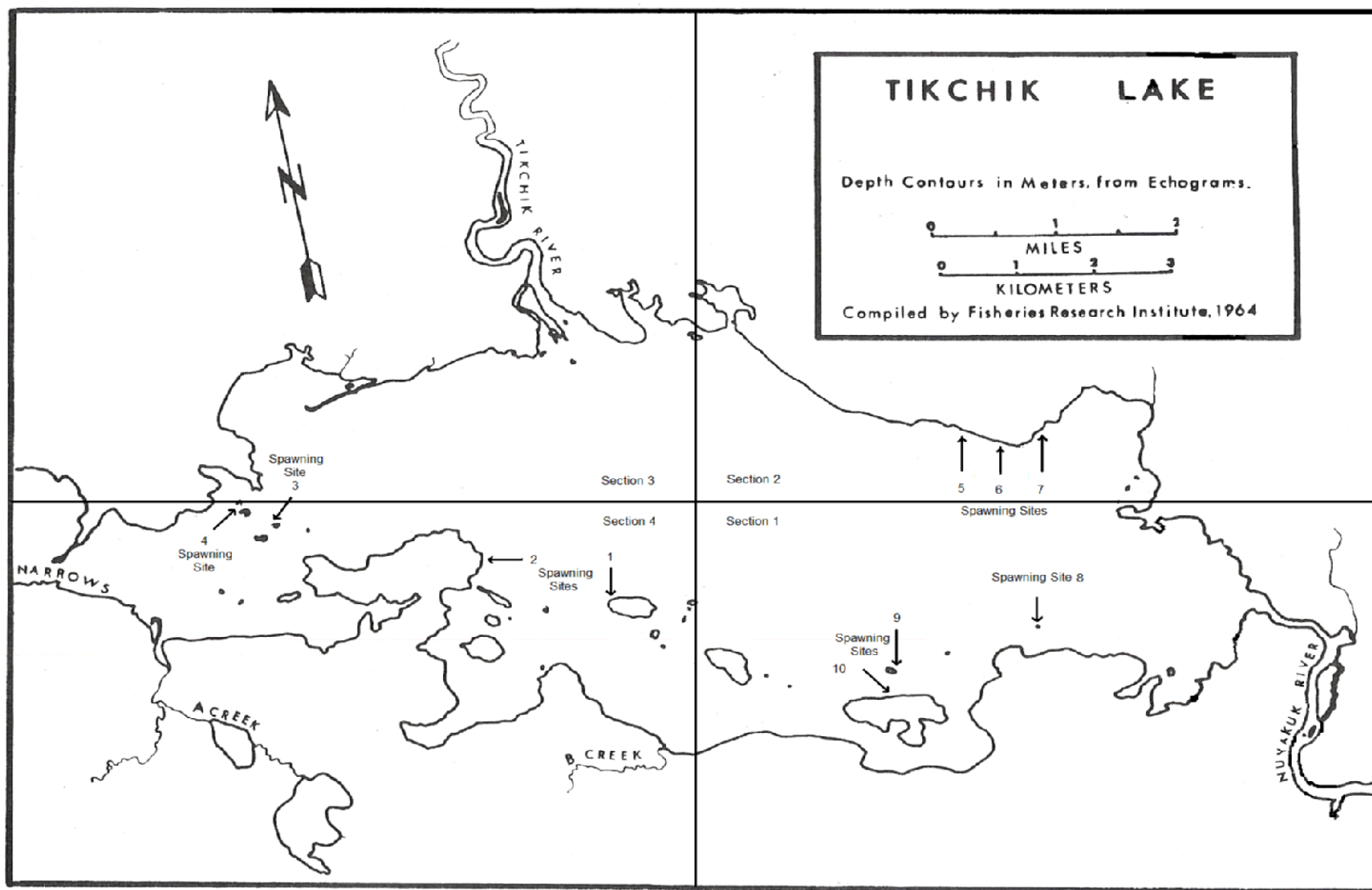


Figure 2.—Tikchik Lake with sampling sections and locations of lake trout spawning sites (arrows).

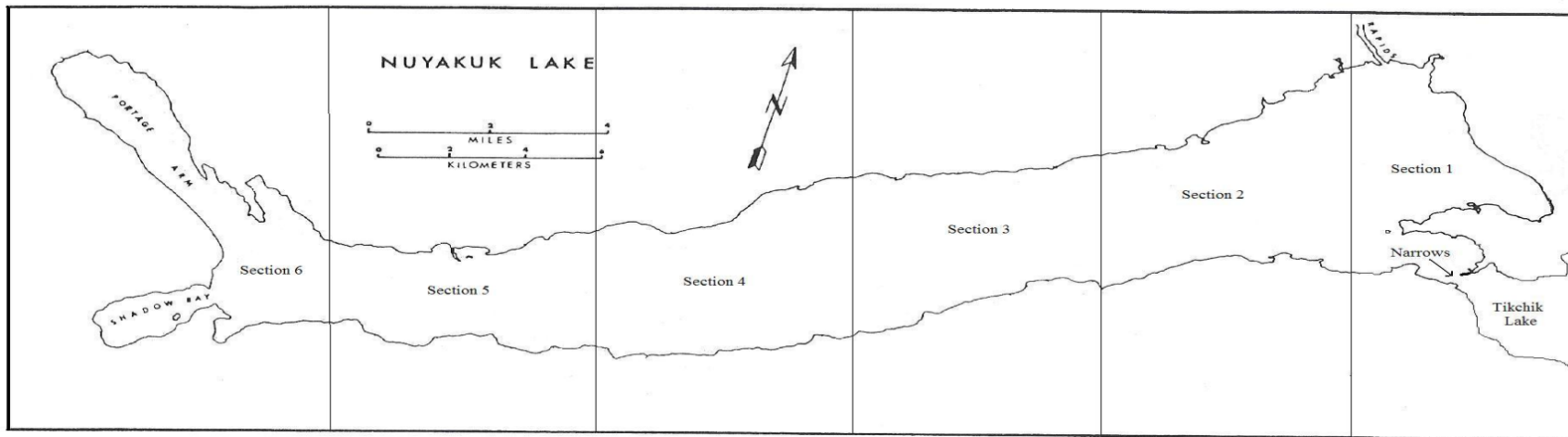


Figure 3.—Nuyakuk Lake with sampling sections.

## Spawning Location Sampling

In some interior Alaskan lakes, spawning generally occurs in mid-September as water temperatures approach 10°C (Burr 1987). Based on these observations from the interior, where the climate is colder, it seemed probable that lake trout in Southwest Alaska spawn in late September and early October. Two fall sampling events were conducted on Tikchik Lake at night, when spawning generally occurs: the first was conducted during the last week of September in 2005, and the second was carried out during the second week of September in 2006. Lake trout generally spawn at night over clean, rocky bottoms of cobble or boulders at depths from less than a meter to 36 m (Martin and Olver 1980, Morrow 1980, Nester and Poe 1987) and these characteristics can be used to successfully identify potential spawning sites (Gunn et al. 1996). Once a possible spawning site was identified, an evaluation of which gear type to use to verify that spawning fish were present was made based upon water depth, substrate type, and distance from shore. If the water at a site was deeper than 2.5 m, contained large boulders, or was more than 60 m from shore, then gill nets were used. If the water was 2.5 m or less, did not appear to contain large boulders (which would hang up on the seine and allow fish to escape), and was 60 m or less from shore, then a seine was used. Lake trout were captured using 2- and 3-inch multifilament gillnets. Gillnets were set and left to soak for up to 30 minutes while the crew searched for other spawning locations. If conditions were favorable for the use of the seine, then a 400 ft × 8 ft beach seine was used. The seine was deployed from a boat in a semi-circle with both ends pulled up on shore, effectively keeping fish from swimming out into deeper water. The middle of the seine was slowly pulled from both sides, drawing fish into shore. All lake trout captured during the fall sampling event were sampled for fork length (FL), weight, sex, Floy-tagged, and released immediately after sampling. Once a spawning site was verified, crews recorded the location using GPS and moved on to look for other sites rather than attempt to catch more fish.

## DATA ANALYSIS

### Radio Tag Data

Aerial survey, boat survey, fixed station, “ground-truthing”, and harvest data were recorded in a fate table with entries as described below.

At each survey, the fate of each radiotagged fish was categorized as  $L_X$ , AL, or R, where

- L = T, N, or TN, denoting lake in which tag was located (Tikchik, Nuyakuk, between Tikchik and Nuyakuk,
- X = NFM denoting “non-fishing mortality” for a fish judged to be dead at the time of the survey, or
  - = FM denoting “fishing mortality” for a fish that was reported harvested, or
  - =  $SA_i$  denoting “spawning area  $i$ ” for a fish found on the  $i^{\text{th}}$  spawning area, or
  - =  $Bi$  denoting “body” for a fish located in the body of the lake ( $i$  denotes section of lake:  $i$  = 1–4 in Tikchik Lake or 1–6 in Nuyakuk Lake).
- AL = “at large”, indicating that the tag was not detected at the time of the survey but was detected in later surveys, and
- R = “removed”; used after an  $L_{\text{NFM}}$  or  $L_{\text{FM}}$  designation.

Given the general movement characteristics of lake trout, it was difficult to precisely define a fate or a time of death. Unlike stream-resident species such as rainbow trout and Arctic grayling, lake trout may spend considerable time in water too deep to be located during radiotracking surveys. This lead to assigning fish the “AL” fate for relatively long periods of time. The NFM fate was assigned to a fish when no movement was observed over periods when other fish showed substantial movement, such as prespawning and postspawning periods, and break-up. In some cases a radio tag was recovered from a mortality.

Spawning areas and time-specific locations of radiotagged lake trout were delineated on maps. Fate data were used to assess the degree of movement of lake trout radiotagged in Tikchik Lake in the following ways:

- 1) Estimate the proportion of lake trout residing in Tikchik Lake in summer 2005 that were found in other lakes during the prespawning, spawning, post-spawning, winter, break-up, and summer 2006 aerial surveys:

$$\hat{p}_{moved,i} = \frac{x_{moved,i}}{n_i} \quad (1)$$

$$\text{var}[\hat{p}_{moved,i}] = \frac{\hat{p}_{moved,i}(1 - \hat{p}_{moved,i})}{n_i - 1} \quad (2)$$

where

- $\hat{p}_{moved,i}$  = the proportion of lake trout that moved from Tikchik Lake to other lakes at the time of survey  $i$  ( $i$  = prespawning, spawning, post-spawning, winter, break-up, or summer 2006 aerial surveys),
- $x_{moved,i}$  = number of radiotagged fish known to have moved from Tikchik Lake to other lakes at the time of survey  $i$ , and
- $n_i$  = number of known functioning radio tags at time of survey  $i$ .

- 2) Assess the degree of movement of radiotagged lake trout among identified spawning areas between the two peak spawning surveys to determine the degree of mixing within the spawning period. This analysis was conducted with contingency table analysis, and a chi-squared test of independence between spawning locations in the first survey and spawning locations in the second survey.

### Length, Weight, and Sex Data

The proportion of lake trout of weight, length, or sex class  $k$ , in the population of lake trout captured in the summer sampling event for each lake was estimated as follows:

$$\hat{p}_k = \frac{n_k}{n} \quad (3)$$

where

- $n_k$  = the total number of lake trout sampled from the lake of weight, length, or sex class  $k$ , and
- $n$  = the number of lake trout sampled from the lake; for the sex proportion, this is the number of radiotagged lake trout for which sex was determined.

The variance of this proportion was estimated as follows:

$$\text{var}(\hat{p}_k) = \frac{\hat{p}_k(1 - \hat{p}_k)}{n - 1}. \quad (4)$$

Empirical cumulative length and weight frequency distributions for the summer lake trout populations of Tikchik and Nuyakuk lakes were compared using Kolmogorov-Smirnov (KS) 2-sample tests.

### Calculation of Yield Potential

The LA model of Evans et al. (1991) was used to calculate 3 yield potentials: 1 for each of Tikchik, Nuyakuk, and Chikuminuk lakes:

$$\log_{10} YP = 0.60 + 0.72 \log_{10} (Area) \quad (5)$$

where

$\hat{Y}P$  = estimated yield potential (kg biomass/year), and

$Area$  = area of lake(s) in ha.

The yield potential for each lake in terms of number of lake trout ( $YP_n$ ) was calculated as follows:

$$YP_n = \frac{\hat{Y}P}{\hat{W}} \quad (6)$$

where  $\hat{W}$  is the estimated mean weight of lake trout (kg per fish) determined from the July sampling program.

The variance in our estimate of YP was calculated as

$$\text{var}[\hat{Y}P_n] \approx YP^2 \frac{\text{var}[W]}{W^4}. \quad (7)$$

The variance estimate for  $YP_n$  is a minimum estimate because uncertainty contributed by the LA model (i.e., in YP) was not quantified in this study.

## RESULTS

### LENGTH AND WEIGHT

#### Tikchik Lake 2005

Sampling in Tikchik Lake occurred over 13 days between 12 July and 1 August, and a total of 143 lake trout were captured and sampled for length and weight. A total of 158 rod hours were spent angling and CPUE was 0.91 lake trout per hour. The most common length class (41%) was 501–550 mm (Figure 4) and the mean length and weight of sampled lake trout was 546 mm (SE 3.93) and 2,013 g (SE 45.65). The number of lake trout captured in each of the 4 sections ranged from 22 in section 1 to 55 in section 4 (Table 1). The CPUE by section ranged from 0.58 for section 1 to 1.15 for section 4 (Table 1). There were no significant differences ( $D = 0.288$ ,  $P = 0.52$ ) in the cumulative length distributions of fish captured in the 4 sections (Figure 5). The 2005 length data were compared to data from 150 lake trout collected by angling in 1990 to



estimate size, maturity, and age composition (Brown and Jaenicke, ADF&G, Douglas, AK, unpublished data). The cumulative length distributions showed no significant difference with K-S tests ( $D = 0.148$ ,  $P = 0.06$ ) between samples collected in 1990 and 2005 (Figure 6). Additional species captured while sampling for lake trout included 11 rainbow trout, 11 Arctic char, and 1 northern pike.

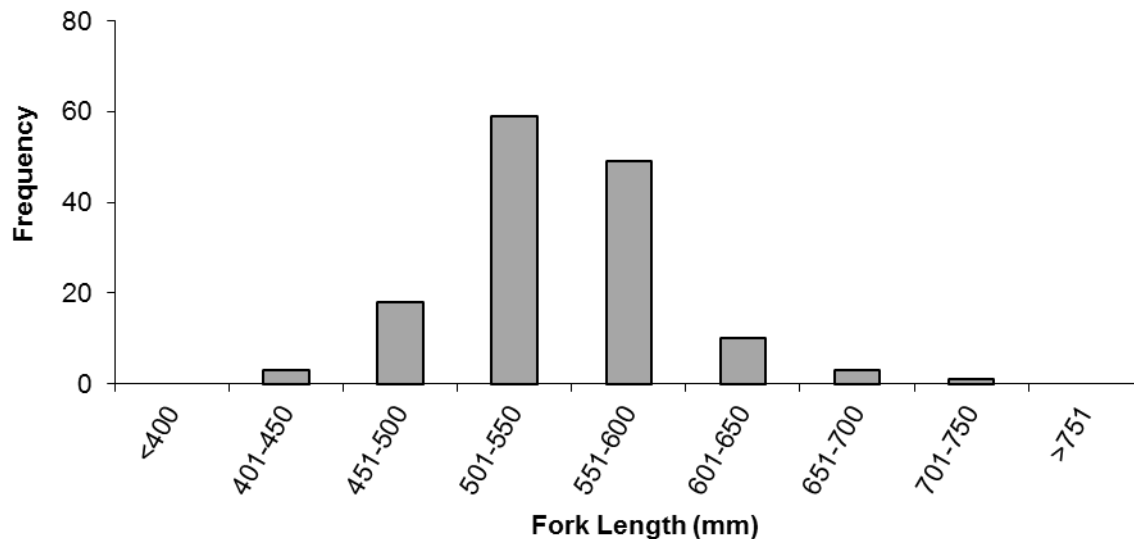


Figure 4.—Length frequency distribution of lake trout from Tikchik Lake captured by angling during summer 2005.

Table 1.—Number of hours sampled, number of lake trout captured, and catch per unit effort (CPUE) of lake trout by angling for each of 4 sections of Tikchik Lake, summer 2005.

Section	Hours	Lake trout	
		Catch	CPUE
1	37.83	22	0.58
2	38.08	42	1.10
3	34.08	24	0.70
4	48.00	55	1.15
Total	157.99	143	3.53
Mean	39.50	35.75	0.88
SE of mean	2.98	7.84	0.14

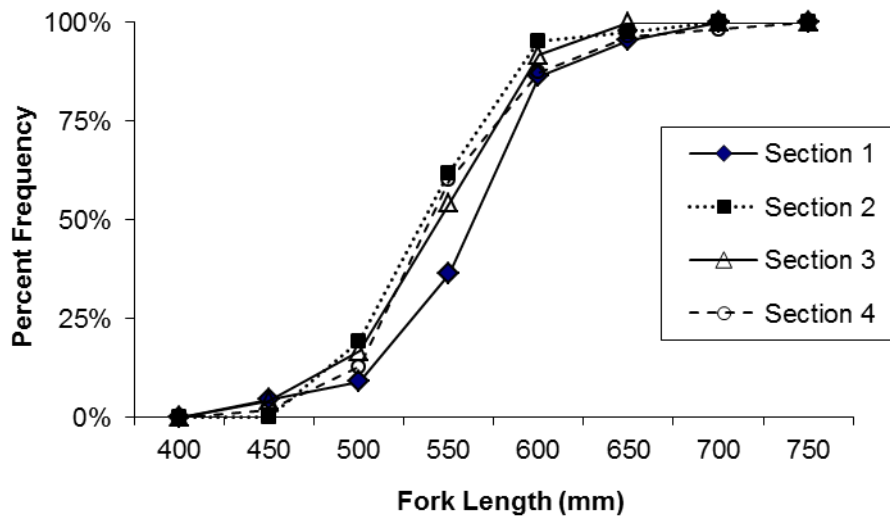


Figure 5.—Length frequency distribution of lake trout captured by angling in each of 4 sections of Tikchik Lake during summer 2005.

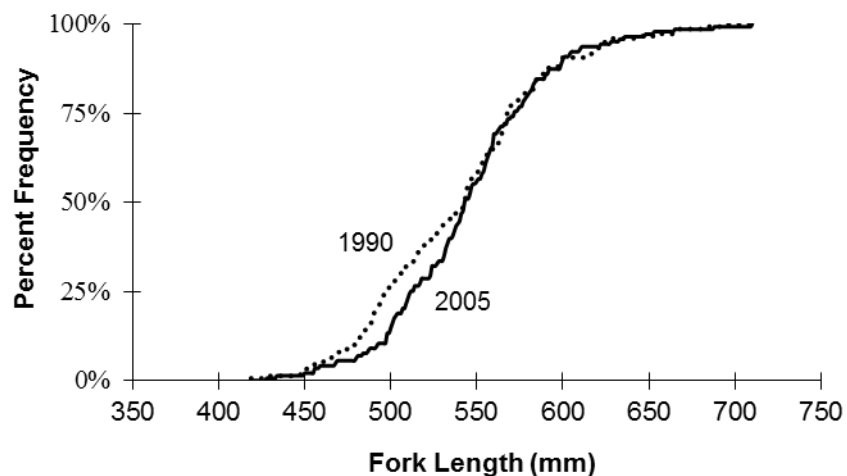


Figure 6.—Length frequency distributions of lake trout captured by angling in Tikchik Lake during summer 1990 and summer 2005.

### Nuyakuk Lake 2005

Nuyakuk Lake was sampled in 2005 from 21 through 23 July and on 2 August; 148 lake trout were captured and measured for length and weight. A total of 61.1 rod hours were spent angling and CPUE was 2.24 lake trout per hour. The most common length class (61%) was 451–500 mm (Figure 7) and the mean length and weight of sampled lake trout was 490 mm (SE 2.73) and

1,390 g (SE 24.84). The number of lake trout captured in each of the 6 sections ranged from 7 in section 1 to 41 in section 4 (Table 2). The CPUE by section ranged from 0.80 for section 1 to 3.80 for section 4 (Table 2). Due to small sample sizes in some sections, sections 1–3 and 4–6 were pooled for a comparison of cumulative length distributions and no significant difference ( $D = 0.160$ ,  $P = 0.31$ ) was found (Figure 8). Thirteen Arctic char were captured in addition to lake trout.

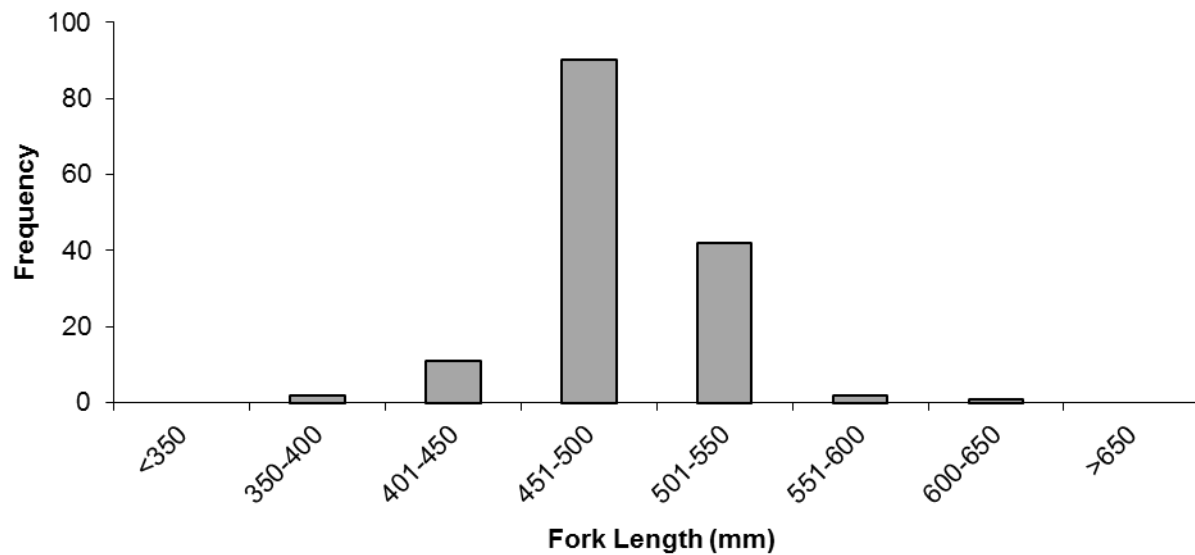


Figure 7.—Length frequency distribution of lake trout from Nuyakuk Lake captured by angling during summer 2005.

Table 2.— Number of hours sampled, number of lake trout captured, and catch per unit effort (CPUE) of lake trout by angling for each of 6 sections of Nuyakak Lake, summer 2005.

Section	Hours	Lake trout	
		Catch	CPUE
1	9.30	7	0.80
2	8.50	12	1.41
3	10.80	27	2.50
4	10.80	41	3.80
5	10.20	30	2.94
6	11.50	23	2.00
Total	61.10	140	13.45
Mean	10.18	23.33	2.24
SE of mean	0.45	5.05	0.44

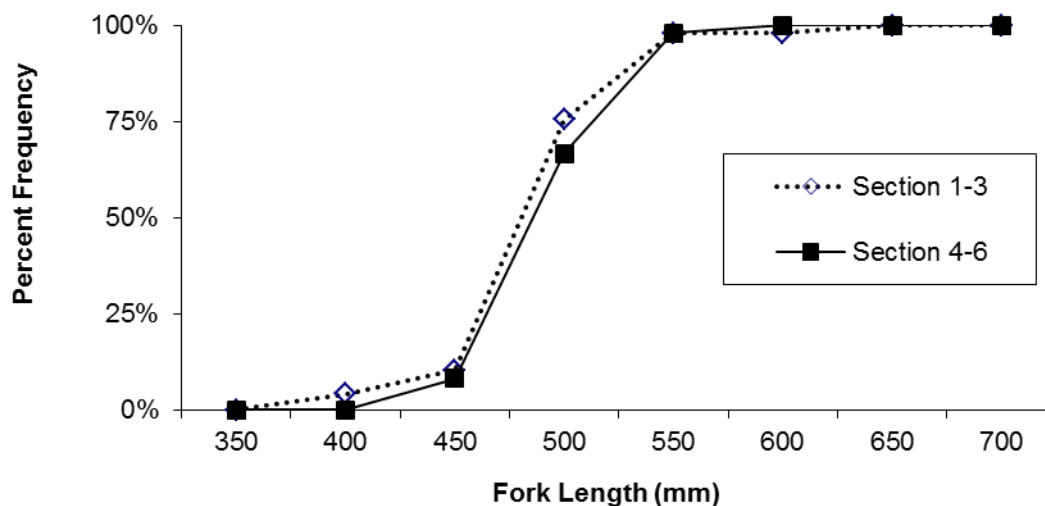


Figure 8.—Length frequency distributions of lake trout captured by angling in sections 1–3 and 4–6 of Nuyakuk Lake during summer 2005.

### Chikuminuk Lake 2006

Chikuminuk Lake was sampled for 3 days from 5 to 7 July 2006, and a total of 133 lake trout were captured and measured for length and weight. A total of 48 rod hours were spent angling and CPUE was 2.77 lake trout per hour. The majority of fish (93%) were between 401 and 500 mm in length (Figure 8) and the mean length and weight of sampled lake trout was 455 mm (SE 2.29) and 998 g (SE 20.59). Fifteen Arctic char were captured in addition to lake trout. A comparison of mean length and weight of lake trout from Chikuminuk, Nuyakuk, and Tikchik lakes indicated that Chikuminuk Lake had the smallest fish ( $P < 0.001$ ) while Tikchik Lake had the largest ( $P < 0.001$ ). Allometric weight-length relationships ( $weight = a \cdot length^b$ ) also differed among the lakes in the  $\alpha$  parameter ( $P < 0.001$ ) but not the  $\beta$  parameter ( $\beta = 2.812$ ); however, the size of the difference in the  $\alpha$  parameters was small ( $\alpha_{Tikchik} = -10.136$ ,  $\alpha_{Nuyakuk} = -10.2$ ,  $\alpha_{Chikuminuk} = -10.33$ ). Fitted curves are shown in Figure 10.

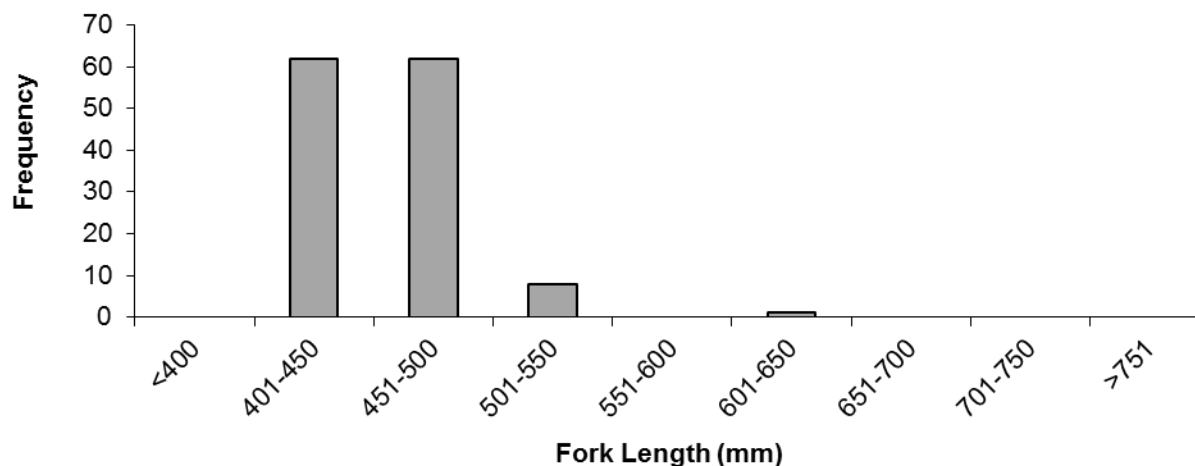


Figure 9.—Length frequency distribution of lake trout from Chikuminuk Lake captured by angling during summer 2006.

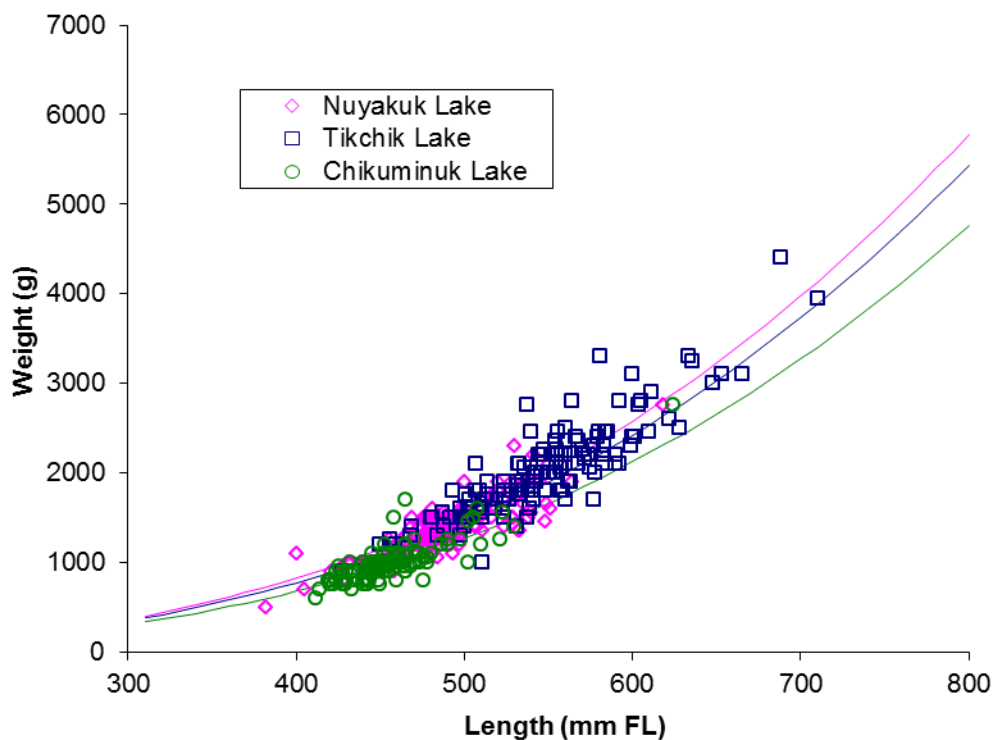


Figure 10.—Length to weight relationships of lake trout sampled from Tikchik and Nuyakuk lakes in July 2005 and from Chikuminuk Lake in July 2006.

## RADIOTELEMETRY

Forty radio transmitters were deployed in male lake trout in Tikchik Lake from 12 July to 1 August 2005 (Appendix A1). It was uncertain how many lake trout would be captured, so transmitter deployment was conducted early in the study to ensure that all transmitters were deployed. Fifty-nine lake trout were examined for implantation. Female fish can be positively identified by visual inspection if the ovipositor extends from the anal vent; visually identified female fish were excluded from surgery. However, fish not displaying an ovipositor may or may not be female. Of the 59 fish examined for sex during surgical implantation, 16 were female and 3 were unidentifiable. A sex ratio could not be estimated because the amount of uncertainty was unknown in visually identifying the sex of a fish without an extruded ovipositor.

Radiotagged fish were tracked through June 2006 and the locations and fates of each fish were recorded (Appendix A1). Twenty-nine radiotagged fish were located at least once; the remaining 11 fish were never located. Five fish were classified as mortalities during the project. Eleven fish were detected by the fixed station at the Narrows between Tikchik and Nuyakuk lakes. Only 1 of these fish entered Nuyakuk Lake for 3 days before returning to the Narrows and Tikchik Lake. The other 23 fish remained in Tikchik Lake and exhibited movement among the 4 sections of the lake during the summer and fall months. During fall 2005, 2 fish were located with a spawning concentration of fish. No pattern was discernible from the summer and fall movements and no aggregations of radiotagged fish were located. In January 2006, 2 areas of the lake appeared to have aggregations of radiotagged fish. Three fish were located near the inlet of the Tikchik River and 6 fish were located just north of the Nuyakuk River outlet. Surveys in May 2006 located a

total of 19 fish, 9 of which were at the inlet of the Tikchik River. In June 2006, 13 fish were located scattered throughout the lake with 3 fish at the Tikchik River inlet and 4 fish at the outlet of the Nuyakuk River.

## YIELD POTENTIAL

Kolmogorov-Smirnov (KS) tests indicated that there were significant differences in the length ( $D = 0.558$ ,  $P < 0.001$ , Figure 11) and weight ( $D = 0.615$ ,  $P < 0.001$ , Figure 12) distributions of lake trout sampled during July from Tikchik and Nuyakuk lakes; fish in Tikchik Lake were larger. As a result of this difference and the lack of substantial movement of fish from Tikchik Lake into Nuyakuk Lake, the LA model estimate of yield was calculated separately for each lake. The surface areas of Tikchik and Nuyakuk lakes are respectively 5,892 ha (Jaenicke et al. 1996) and 14,400 ha (Yanagawa 1967). There is no length restriction on lake trout harvest in Bristol Bay; however, most fish sampled in Tikchik and Nuyakuk lakes were greater than 450 mm FL, which is approximately 18 inches total length, the minimum length of harvest in some waters of interior Alaska. As a result, 450 mm FL was selected as the minimum length for estimating yield potential. The mean weight of fish *at least* 450 mm FL from Tikchik Lake was 2.0 kg (SE 0.045). The calculated yield potential for Tikchik Lake was 2,063 kg biomass/year or 1,017 fish/year (SE 22.5). The mean weight of fish at least 450 mm FL from Nuyakuk Lake was 1.4 kg (SE 0.023). The calculated yield potential for Nuyakuk Lake was 3,926 kg biomass/year or 2,729 fish/year (SE 43.6). In Chikuminuk Lake, almost half the fish sampled (47%) were between 400 and 450 mm FL and all fish were at least 400 mm FL. As a result, yield potential for Chikuminuk Lake was estimated for fish at least 400 mm FL. Chikuminuk Lake has a surface area of 10,043 ha (Patrick Walsh, USFWS, personal communication) and calculated yield for lake trout was 3,029 kg biomass/year or 3,035 fish/year (SE 76.4).

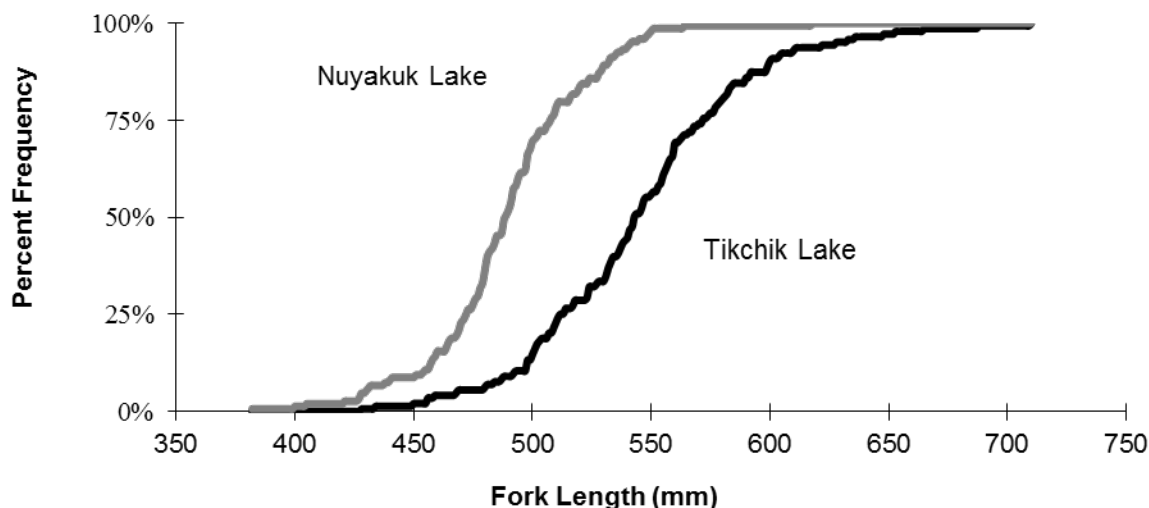


Figure 11.—Length frequency distributions of lake trout captured by angling in Tikchik and Nuyakuk lakes during summer 2005.

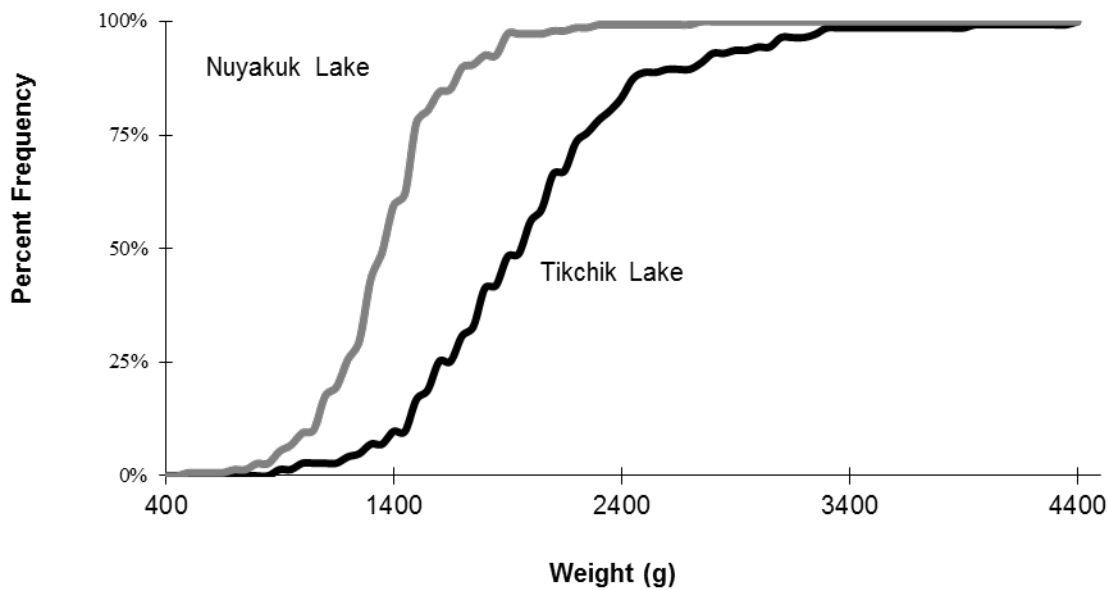


Figure 12.—Weight frequency distributions of lake trout captured by angling in Tikchik and Nuyakuk lakes during summer 2005.

## SPAWNING LOCATIONS

From 23 to 30 September 2005 and 11 to 15 September 2006, attempts were made to locate spawning areas in Tikchik Lake. A combination of radiotracking, visual observations, and netting with gillnets and beach seines was used. Radiotracking and visual observations using spot lights were conducted at dusk and at night from a skiff. The entire shoreline of the lake and most of the shoreline around islands were visually examined for suitable lake trout spawning habitat as well as concentrations of fish. Locations determined to be suitable spawning habitat were set with gillnets or were seined during the night. Gillnets were set for a total of 158 hours at 30 different sites on the lake in 2005 and for 18.7 hours at 10 sites during 2006. The beach seine was only used twice due to the lack of observed concentrations of lake trout. No fish were caught with the beach seine. Five spawning locations were found in 2005 with 5 additional sites located in 2006 (Figure 2). One spawning site was located with the aid of radiotelemetry, 7 locations were found by observing fish at night and setting nets to verify their maturity, and 3 locations were found by setting gillnets in areas that appeared to have suitable spawning habitat for lake trout.

A total of 17 male, 12 female, and 4 unknown lake trout were sampled during fall 2005, 22 with gill nets and 11 with hook and line. Of the 33 fish, 29 were spawning or had spawned that fall. Of these, 18 were actively spawning and 11 (6 males and 5 females) had completed spawning. A total of 31 male and 4 female lake trout were sampled with gillnets during fall 2006. All fish were in spawning condition, with 1 female spawned out. The length of sexually mature fish sampled in fall and summer 2005 and in fall 2006 ranged from 469 to 835 mm FL (Figure 11). The smallest sexually mature male sampled was 469 mm FL and the smallest sexually mature female was 502 mm FL. In addition to lake trout, the nets captured 57 white fish, 16 Arctic grayling, 8 northern pike, 5 least cisco, 2 burbot, 1 sockeye salmon, and 1 rainbow trout.

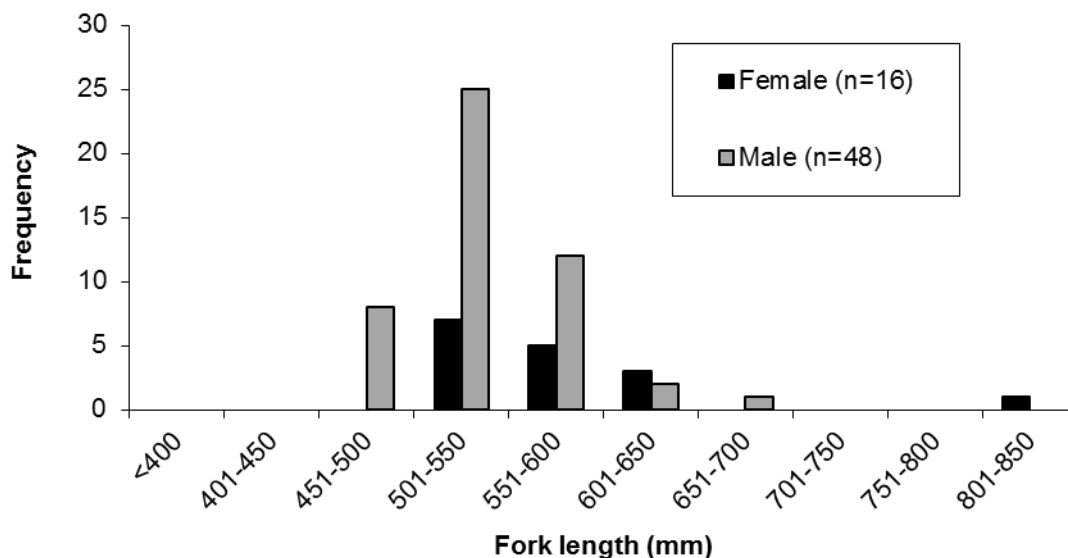


Figure 13.—Length distribution of sexually mature lake trout sampled from Tikchik Lake in September 2005 and 2006.

## DISCUSSION

Tikchik and Nuyakuk lakes were sampled for lake trout at the same time and with the same gear and methods. There was a higher CPUE in Nuyakuk Lake, indicating higher lake trout abundance than Tikchik Lake. There was also a clear difference in the cumulative length and weight distributions of lake trout between the two lakes. In addition, there was no significant movement of fish from Tikchik Lake to Nuyakuk Lake. Apparently, the narrows between the two lakes provides enough separation to develop unique population parameters for each lake trout population. As a result, LA model estimates of yield potential were conducted separately for Tikchik and Nuyakuk lakes.

To attain reliable estimates of yield potential for each lake, it was important to collect a representative sample of the lake trout population. The sampling protocol was designed to support this assumption. At Tikchik Lake, a balance was struck between sampling fish throughout the lake and sampling in proportion to CPUE by lake section. That is, a higher proportion of sampling time was spent in section 4 than section 3 due to a higher CPUE after the first 2 weeks of sampling. Furthermore, because there was evidence from telemetry data of trout mixing among lake sections, our ability to obtain a representative sample from the lake was likely enhanced. Sampling was distributed along the entire length of the north shore of Nuyakuk Lake and sampling occurred around most of the shoreline and islands of Chikuminuk Lake.

A comparison of harvest data to the estimated yield of lake trout in the Tikchik Lake system indicates that the populations are not heavily exploited. Healy (1978) recommended that sustainable yields of lake trout should not exceed 0.5 kg/ha. From 2001 to 2005, the harvest of lake trout in the entire Tikchik Lake system has averaged 150 lake trout per year, while the catch has averaged 4,114 lake trout per year (Jennings et al. 2004, 2006a-b, 2007, 2009). Angling pressure is currently low and effort for each individual lake in the Tikchik Lake system is not discernible with the Division of Sport Fish Statewide Harvest Survey. This indicates that the



harvest for each lake is very low and there is no concern that potential yield (approximately 1,000 to 3,000 fish/year, depending on lake) is exceeded at this time.

The findings of this study were compared to previous work conducted on Tikchik Lake in 1990, showing that size composition of lake trout captured by angling has not changed significantly since 1990. In addition, minimum lengths of mature males and females were similar between 1990 and 2005 (475 and 487 mm FL for males and females respectively in 1990 versus 469 and 502 mm FL for males and females respectively in 2005). The smallest mature lake trout sampled in Tikchik Lake was larger than the length at which 50% of lake trout were mature for 11 lakes in interior Alaska (range of 335 to 476 mm FL) (Burr 1993). Tikchik lake has a larger surface area than the interior lakes and a positive correlation has been found between lake size and the length at which lake trout mature (Burr 1993), with a larger length at maturity for larger lakes. In addition, lake trout from lakes with a large number of forage fish species, such as Tikchik Lake with several species of coregonids and juvenile sockeye salmon, generally grow faster and mature at a larger size (Burr 1993). Age estimation from otoliths for lake trout in Tikchik Lake indicate that fish in this size range (approximately 450–500 mm FL) are between 7 and 8 years of age<sup>2</sup>, which is a common age at maturity for lake trout populations in southern and interior Alaska (Burr 1987).

Lake trout spawning locations have been documented on several lakes in interior Alaska. Some difficulty was experienced in locating spawning sites on Tikchik Lake. Aerial telemetry surveys conducted in mid-September 2005 did not indicate that fish were moving into shallow areas for spawning. In addition, the water temperature was 11°C, slightly warmer than Susitna Lake where spawning commences when water temperatures reach 10°C (Burr 1987). As a result, the field crew was deployed during the fourth week of September, when the water temperature had decreased to 10°C. However, it appeared that sampling was too late and had missed the peak of spawning. Of the sexually mature fish that were sampled, 38% (11 of 28) were already spawned out, and the other sexually mature fish appeared to be actively spawning and nearly spawned out. In addition, not many fish (up to 7) were observed at the sites when attempts were made to capture spawning fish, likely due to the fact that many of the fish had already completed spawning.

Based on these results, sampling was begun earlier in September during 2006. The water temperature during sampling in 2006 was 13.5°C and groups of up to 15 lake trout were observed spawning. Only 1 spawned-out fish was sampled, suggesting that spawning had commenced recently. These findings indicate that spawning in Tikchik Lake may be more temporally spread out than lakes in the interior. This may be due to a milder climate and a more gradual cooling of lake waters in the fall compared to the interior of Alaska, protracting the spawning period. Assuming a similar water temperature decrease during 2005 and 2006, spawning likely commences during the first week of September and continues through early October.

Ten spawning sites were located in Tikchik Lake; however, given the size of the lake and the number of locations that had suitable spawning habitat, and the fact that no large concentrations

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<sup>2</sup> Brown, A. Unpublished. *Age composition and growth rates for lake trout *Salvelinus namaycush* in Tikchik Lake, Southwest Alaska in 1990*. Draft 1997 report, available through Alaska Department of Fish and Game, Division of Sport Fish, Research and Technical Services, Anchorage.

(> 20 fish) were found at any given site, it is possible that additional spawning sites were not located. For comparison, a total of 18 spawning sites have been documented on Lake Louise, which is 600 ha larger (C. Schwanke, Sport Fish Biologist ADF&G, Glennallen, personal communication) and 12 sites have been documented on Paxson Lake, which is smaller (1,575 ha) (Scanlon 2004). Lake trout have been shown to exhibit high fidelity to specific spawning sites from year to year (Gunn et al. 1996) and the spawning sites documented by this study can be used for future research on Tikchik Lake. However, it will be difficult to estimate abundance at spawning sites because spawning is protracted over a large time frame and area, in contrast to lake trout in interior Alaska, which spawn during a 2 week time frame. If future studies occur, researchers will have to rely predominantly on gillnets to sample fish at spawning locations. Only 4 of the 10 spawning locations (1, 4, 5 and 6; Figure 2) appeared suitable for beach seining (Appendix B1). The remaining locations had a combination of large boulders, a steep gradient, or lack of a beach to seine from.

The Tikchik Lake system provides examples of relatively unexploited lake trout populations. Catch per unit effort for Tikchik, Nuyakuk, and Chikuminuk lakes, as an index of abundance, seems to indicate healthy populations of lake trout. Tikchik Lake had a lower CPUE than the other lakes, which may indicate a lower abundance of lake trout. One possible explanation for this may be that Tikchik Lake was the only lake where rainbow trout were also sampled. Furthermore, Tikchik Lake has shallower shoreline habitat than other lakes, with some areas of aquatic vegetation that, based on visual and angling observations, support a larger northern pike population than Nuyakuk and Chikuminuk lakes. Marshall (1996) has documented a negative relationship between lake trout relative abundance and fish species diversity, especially with additional piscivorous species.

It was hoped that a sampling protocol to monitor lake trout in the study lakes could be developed based on spawning sites located in this study. Given the duration of the spawning period and the lack of large concentrations of fish, this may not be feasible. However, this study does provide an index of relative abundance with angling CPUE during July that can be used as an indicator of lake trout population health. In addition, size compositions can be compared among years when data were collected. Sampling for monitoring should be conducted during the same time frame and with the same techniques and gear to validate any comparisons.

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**APPENDIX A: LOCATION AND FATE OF RADIOTAGGED  
LAKE TROUT IN TIKCHIK LAKE DURING SURVEYS IN  
2005 AND 2006**

Appendix A1.–Locations and fates of radiotagged lake trout in Tikchik Lake during surveys in 2005 and 2006.

Frequency/ Code	Date deployed	Sex	FL (mm)	Floy-tag	Capture location (subarea)	Survey period <sup>a</sup>					
						Prespawning Aug 2005	Spawning Sep 2005	Postspawning Nov 2005	Winter Jan 2006	Break-up May 2006	Early summer Jun 2006
2.645/15	19 Jul	M	514	400568	1	AL	T <sub>NFM</sub>	R	R	R	R
2.645/16	25 Jul	M	480	401254	2	T <sub>B1</sub>	T <sub>B4</sub>	T <sub>B1</sub>	T <sub>B1</sub>		
2.645/17	14 Jul	M	592	400137	3						
2.645/18	18 Jul	M	547	400573	1	AL	T <sub>SA1</sub>				
2.645/19	14 Jul	M	564	400143	2	AL	AL	T <sub>B4</sub>	T <sub>B2</sub>	T <sub>B2</sub>	T <sub>B1</sub>
2.645/20	12 Jul	M	543	400131	3	AL	AL	AL	AL	AL	T <sub>B3</sub>
2.645/21	20 Jul	M	514	400559	2	AL	T <sub>B2</sub>	AL	T <sub>B2</sub>	T <sub>B2</sub>	T <sub>B2</sub>
2.645/22	18 Jul	M	628	400153	3	AL	AL	AL	AL	AL	T <sub>B3</sub>
2.645/23	25 Jul	M	541	401259	2	AL	T <sub>B4</sub>	AL	AL	T <sub>B3</sub>	
2.645/24	19 Jul	M	532	400565	1	AL	T <sub>SA1NFM</sub>	R	R	R	R
2.675/15	20 Jul	M	509	400600	3	AL	AL	AL	T <sub>B3</sub>		
2.675/16	25 Jul	M	504	400550	4						
2.675/17	14 Jul	M	648	400141	2	AL	AL	T <sub>B3</sub>	AL	T <sub>B3</sub>	
2.675/18	14 Jul	M	590	400138	4	AL	AL	T <sub>NFM</sub>	R	R	R
2.675/19	12 Jul	M	568	400133	3	AL	AL	AL	T <sub>B1</sub>	T <sub>B3</sub>	
2.675/20	20 Jul	M	534	400167	4	AL	AL	AL	AL	T <sub>B4</sub>	
2.675/21	20 Jul	M	550	400555	2						
2.675/22	20 Jul	M	553	400166	4	AL	AL	AL	T <sub>B4</sub>	T <sub>B3</sub>	
2.675/23	15 Jul	M	539	400148	2	AL	TN	AL	AL	T <sub>NFM</sub>	R
2.675/24	30 Jul	M	537	401287	3	T <sub>B2</sub>	T <sub>B3</sub>	AL	T <sub>B3</sub>	T <sub>B3</sub>	
2.795/15	28 Jul	M	604	401274	4	AL	T <sub>B2</sub>	AL	AL	AL	T <sub>B3</sub>
2.795/16	15 Jul	M	524	400149	4						
2.795/17	25 Jul	M	551	401253	2	T <sub>B2</sub>	AL	AL	AL	AL	T <sub>B3</sub>
2.795/18	25 Jul	M	469	400125	4						
2.795/19	29 Jul	M	688	401160	2	TN	AL	AL	T <sub>B2</sub>	T <sub>B2</sub>	T <sub>B1</sub>
2.795/20	30 Jul	M	524	401163	3	AL	AL	AL	T <sub>B3</sub>	T <sub>B3</sub>	
2.795/21	28 Jul	M	498	401278	4	AL	AL	AL	AL	T <sub>B4</sub>	

-continued-

Appendix A1.–Part 2 of 2.

Frequency/ Code	Date deployed	Sex	FL (mm)	Floy-tag	Capture location (subarea)	Survey period <sup>a</sup>					
						Prespawning Aug 2005	Spawning Sep 2005	Postspawning Nov 2005	Winter Jan 2006	Break-up May 2006	Early summer Jun 2006
2.795/22	20 Jul	M	563	400173	3	TN	T <sub>B2</sub>	AL	AL	T <sub>B4</sub>	
2.795/23	20 Jul	M	538	400171	4	TN	AL	T <sub>NFM</sub>	R	R	
2.795/24	13 Jul	M	553	400134	4	AL	AL	AL	T <sub>B2</sub>		
2.824/15	29 Jul	M	501	401281	4	TN	T <sub>B4</sub>	AL	AL	T <sub>B1</sub>	T <sub>B1</sub>
2.824/16	1 Aug	M	568	401165	1	AL	AL	AL	AL	T <sub>B1</sub>	
2.824/17	15 Jul	M	524	400151	4						
2.824/18	13 Jul	M	511	400135	2	AL	T <sub>B4</sub>	AL	T <sub>B3</sub>	T <sub>B3</sub>	T <sub>B4</sub>
2.824/19	19 Jul	U	600	400566	1	AL	T <sub>B1</sub>	T <sub>B2</sub>	AL	T <sub>B1</sub>	T <sub>B1</sub>
2.824/20	20 Jul	U	558	400551	1	AL	TN	AL	AL	T <sub>B1</sub>	T <sub>B2</sub>
2.824/21	25 Jul	M	510	401260	2						
2.824/22	19 Jul	M	533	400156	3						
2.824/23	28 Jul	M	562	401277	4	AL	TN	AL	AL	T <sub>B3</sub>	
2.824/24	19 Jul	U	541	400564	1	AL	T <sub>B2</sub>				

<sup>a</sup> Fate categories are listed according to the definitions given in the Data Analysis section of the Methods.





**APPENDIX B: LOCATION AND DESCRIPTION OF LAKE  
TROUT SPAWNING SITES IN TIKCHIK LAKE.**

Appendix B1.–Location and description of lake trout spawning sites in Tikchik Lake.

Spawning Site	GPS location	Beach seine	Description
Site 1		Yes	Northwest end of island. Cobble mixed with gravel. Gradual drop from 0.6 to 1.5 m depth. Fifteen meters from island substrate turns to sand.
Site 2	N 59° 57.353 W 158° 22.431	No - no beach, too deep	Shoreline along west end of lake. Large cobble and boulder. Ten meters from shore depth drops quickly to 4 m depth with similar substrate.
Site 3		No - no beach, too deep	North side of small island. Boulder and bedrock. Eighteen meters from shore depth drops quickly.
Site 4	N 59° 58.002 W 158° 25.930	Yes	Northwest end of island. Gravel and small cobble substrate. Gradual gradient to 2 m depth approx. 23 m from shore where substrate turns to sand.
Site 5	N 59° 57.925 W 158° 15.840	Yes	Northeast shore of lake. Large cobble becoming sand 12 m out. Gradual gradient to 3 m depth at sand.
Site 6	N 59° 57.838 W 158° 15.462	Yes	Northeast shore of lake. Large cobble becoming sand 12 m out. Gradual gradient to 3 m depth at sand.
Site 7	N 59° 57.692 W 158° 14.540	No - large cobble, gradient	Northeast shore of lake. Large cobble becoming sand 15 m out. Gradual gradient for 6 m then drops to 3 m depth before a steep drop.
Site 8		No - no beach, large substrate	North side of small island. Large cobble, boulders and bedrock. Depth range of 0.6 to 2.5 m. Five meters from island substrate turns to sand.
Site 9	N 59° 56.085 W 158° 16.790	No - no beach, large substrate	Point on east side of island and along shore on the north shore of the island. Medium to large cobble out to 24 m. Gradual gradient to 3 m depth off east point and steeper gradient on north side.
Site 10	N 59° 58.344 W 158° 25.574	No - no beach, too deep, large substrate	North side of Eagle Island. Cobble and boulder. Steep gradient out to 15 m.